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Research Article

Performance Evaluation of Urban Drainage Systems Under Sedimentation and Solid Waste Influence

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Abstract

Urban flooding remains a persistent challenge in developing cities, often attributed not only to insufficient drainage capacity but also to operational issues such as sedimentation and solid waste accumulation. This study aims to evaluate the hydraulic performance of an existing urban drainage system and to determine its capacity in accommodating design discharge generated from rainfall and domestic wastewater in a residential area of Pontianak, Indonesia. The research applies integrated hydrological and hydraulic analyses using both primary and secondary data. Field observations were conducted to obtain channel dimensions, sedimentation levels, and existing physical conditions. Meanwhile, secondary data consisted of ten years of maximum daily rainfall records. Rainfall frequency analysis was carried out using the Gumbel distribution, while rainfall intensity was estimated using the Mononobe method. The rational method was then employed to calculate design discharge, which was compared with the existing channel capacity under both ideal and sediment-affected conditions. The findings reveal that the drainage system is hydraulically capable of conveying the design discharge under optimal conditions. However, the effective capacity is significantly reduced due to sediment deposition, solid waste accumulation, structural deterioration, and uneven road surfaces. These factors collectively reduce flow efficiency and contribute to localized flooding. This study highlights that drainage system performance is strongly influenced by maintenance practices and environmental conditions, emphasizing the need for integrated management strategies to achieve sustainable urban flood mitigation.

Keywords: *Design Discharge; Flood Mitigation; Hydraulic Perfomance; Sedimentation*

INTRODUCTION

Drainage is a technical effort designed to reduce excess water in a land or area, whether originating from rainfall, seepage, or irrigation, so that the land can function optimally. In urban environments, drainage systems are considered essential infrastructure components that play a vital role in preventing waterlogging and flooding [1], [2], [3]. These systems consist of interconnected structures that function collectively to convey excess water away from inhabited areas. Proper drainage ensures that urban activities can proceed without disruption caused by standing water [4]. However, the effectiveness of a drainage system depends largely on its design capacity and its ability to handle varying volumes of incoming water. When the volume of water entering the system exceeds its capacity, overflow may occur, leading to flooding [5], [6]. This condition is often associated with inadequate planning or underestimation of hydrological conditions during the design stage. Therefore, proper planning and design are fundamental to ensuring that drainage systems function efficiently. In addition to design considerations, maintenance plays a crucial role in sustaining system performance. Community participation is also necessary to support the long-term functionality of drainage systems in urban areas.

Urban drainage systems are generally composed of various supporting structures such as culverts, channels, control gates, and pumping stations. These components work together to regulate and direct water flow toward receiving bodies such as rivers or reservoirs. Ideally, the design of such systems is based on hydrological analysis to determine the expected discharge under specific rainfall conditions [7], [8]. The hydraulic capacity of the channel is then adjusted to ensure that water can flow without exceeding the system limits [9], [10]. However, in practice, the performance of drainage systems is influenced not only by design parameters but also by physical conditions in the field [11], [12], [13], [14]. Over time, factors such as sediment deposition and structural deterioration can significantly reduce the effectiveness of the system [15], [16], [17]. In addition, the accumulation of solid waste within drainage channels can obstruct flow and increase hydraulic resistance. These conditions can alter the original design assumptions and reduce the system’s capacity to convey water. As a result, drainage systems that are theoretically adequate may fail under real conditions. This highlights the importance of evaluating drainage performance beyond design calculations.

Flooding or water stagnation frequently occurs in certain urban areas, particularly during periods of high rainfall intensity. In cities, rainfall is typically directed into artificial drainage channels, which are expected to transport water efficiently to downstream systems [18], [19], [20], [21]. However, urban flooding often exhibits different characteristics compared to natural flooding, as it is heavily influenced by infrastructure conditions [22], [23], [24], [25]. One example of such a problem occurs in the residential area of Gang Siliwangi, Jalan Pangeran Natakusuma in Pontianak. Field observations indicate that flooding occurs when rainfall intensity is high and persists for an extended duration. Residents reported that water begins to accumulate on roads and in residential yards within one to two hours of continuous rainfall. In some cases, floodwater even enters residential buildings, causing inconvenience and potential damage. These observations suggest that the drainage system in the area may not be functioning optimally under real conditions. The problem is likely influenced by a combination of hydrological factors and physical constraints within the drainage network. Therefore, it is necessary to conduct a detailed evaluation of the existing drainage system to understand its actual performance.

Recent studies on urban drainage systems have primarily emphasized advanced modeling approaches, system optimization, and sustainable concepts such as Sustainable Urban Drainage Systems (SuDS), focusing on decision-support tools, hydrological simulations, and resilience enhancement under climate change scenarios [26], [27], [28]. Additionally, several studies have evaluated drainage performance using multi-criteria decision-making frameworks, remote sensing, and real-time flood forecasting models, contributing to improved large-scale system assessment and planning [13], [29], [30]. Despite these advancements, most existing research assumes ideal operational conditions and predominantly focuses on design capacity and modeling accuracy, with limited attention given to actual field conditions, particularly in developing urban areas where maintenance practices are often insufficient [6], [31]. Furthermore, while some studies acknowledge the role of maintenance and environmental factors, they rarely provide detailed quantitative analysis of how sedimentation, solid waste accumulation, and structural degradation affect hydraulic capacity and flow performance in existing drainage systems [24], [32]. Consequently, there remains a lack of integrated studies that combine hydrological analysis, hydraulic capacity evaluation, and field-based observations to explain the discrepancy between theoretical design capacity and actual drainage performance. This gap leads to an incomplete understanding of why urban flooding persists even in areas where drainage systems are technically adequate, highlighting the need for a more comprehensive, field-oriented evaluation approach.

This study aims to evaluate the performance of the existing drainage system in a residential area by analyzing its capacity to accommodate water discharge under both ideal and actual conditions. The research focuses on assessing the ability of the drainage channels to convey combined discharge from rainfall and domestic wastewater. In addition, the study examines the influence of sedimentation on the reduction of effective channel capacity. The impact of solid waste accumulation on flow obstruction and hydraulic performance is also analyzed. Furthermore, the study investigates how structural conditions of the drainage system affect overall functionality. Hydrological analysis is conducted to estimate rainfall discharge, while hydraulic analysis is used to determine channel capacity. Field observations are incorporated to provide a realistic representation of existing conditions. The comparison between design capacity and actual performance is used as the basis for evaluation. This approach allows for a comprehensive understanding of the factors contributing to drainage inefficiency. Ultimately, the study aims to provide recommendations for improving drainage system performance through better design, maintenance, and management practices.

METHODS

Research Design

This study employed a quantitative analytical approach integrating hydrological and hydraulic analyses to evaluate the performance of an existing urban drainage system. The research was designed to systematically assess whether the current drainage capacity is sufficient to accommodate the design discharge generated from rainfall and domestic wastewater contributions. The analytical framework combined mathematical modeling with field-based observations to ensure both theoretical accuracy and practical relevance. In addition to numerical evaluation, a qualitative assessment was conducted to identify physical and environmental factors influencing system performance, including sedimentation, solid waste accumulation, and structural deterioration of the drainage channel.

Study Area

The study was conducted in a residential drainage network located in Gang Siliwangi, Jalan Pangeran Natakusuma, Pontianak, Indonesia. The drainage system serves a densely populated residential catchment consisting of approximately 43 housing units, with a total channel length of about 458.6 meters. The area represents a typical urban drainage setting in developing regions, where drainage systems function as combined channels carrying both stormwater runoff and domestic wastewater. The relatively flat topography, combined with high rainfall intensity, makes the study area particularly vulnerable to waterlogging and localized flooding events.

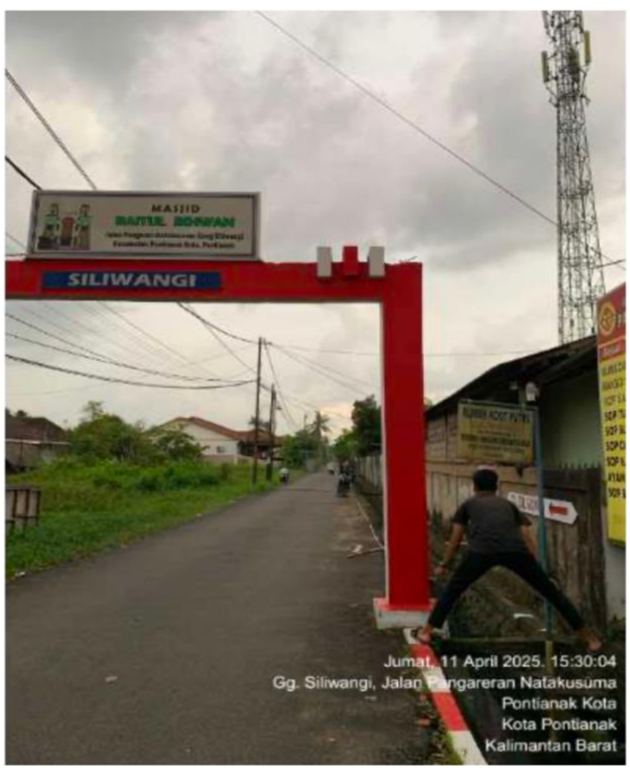

Figure 1. Gang Siliwangi

Data Collection

The data used in this study consisted of both primary and secondary sources to ensure comprehensive analysis and validation.

1. **Primary Data**

   Primary data were collected through direct field observations and on-site measurements. These observations aimed to capture the actual physical and operational conditions of the drainage system. The parameters measured included channel dimensions (width, depth, and length), flow direction, channel alignment, and sediment thickness within the channel bed. In addition, visual inspections were conducted to assess the structural condition of the drainage system, including cracks, blockages, and vegetation growth. Information on surrounding land use and catchment characteristics was also recorded to support hydrological parameter estimation.

2. Secondary data

   Secondary data were obtained from relevant institutions and technical references. These included maximum daily rainfall data over a 10-year period, which were used as the basis for hydrological analysis. Additionally, technical standards and guidelines related to urban drainage design were utilized to ensure that all calculations and evaluations followed established engineering practices.

Hydroligical Analysis

Hydrological analysis was performed to estimate the design discharge (Qr) as the primary input for evaluating drainage capacity. The analysis consisted of several sequential steps.

1. **Rainfall Frequency Analysis**

   Rainfall frequency analysis was conducted using the Gumbel distribution method to estimate design rainfall corresponding to a selected return period. This method was chosen due to its suitability for analyzing extreme hydrological events and its widespread application in urban drainage studies. The analysis aimed to determine the magnitude of rainfall that is likely to occur within a specified recurrence interval.

2. **Rainfall Intensity Estimation**

   Rainfall intensity was calculated using the Mononobe equation, which converts daily rainfall data into short-duration rainfall intensity based on the time of concentration. This approach allows for a more accurate representation of rainfall characteristics affecting urban runoff, particularly in small catchment areas.

3. **Time of Concentration (Tc)**

   The time of concentration was determined as the total time required for runoff to travel from the most distant point of the catchment to the outlet of the drainage system. It was calculated by combining inlet time, representing overland flow, and flow travel time within the drainage channel. This parameter plays a critical role in determining rainfall intensity and peak discharge.

4. **Runoff Coefficient (C)**

   The runoff coefficient was estimated based on the characteristics of land use within the drainage catchment. Given the mixed nature of the study area, a representative value was determined to reflect the proportion of rainfall that contributes to surface runoff. This coefficient accounts for surface permeability, vegetation cover, and built-up areas.

5. **Design Discharge Calculation**
   The design discharge was calculated using the Rational Method, which relates rainfall intensity, runoff coefficient, and catchment area. This method was selected due to its simplicity and suitability for small urban catchments. The resulting discharge represents the peak flow that must be accommodated by the drainage system under design conditions.

Hydraulic Analysis

Hydraulic analysis was conducted to evaluate the capacity of the existing drainage channel to convey the calculated design discharge. The analysis involved the computation of key hydraulic parameters, including cross-sectional area (A), wetted perimeter (P), hydraulic radius (R), flow velocity (V), and channel discharge (Qs). Flow velocity and discharge capacity were determined using the Manning equation, which incorporates channel roughness and slope as governing factors. To provide a realistic evaluation, the analysis was performed under two different conditions. The first condition assumed an ideal channel without sedimentation, representing the maximum theoretical capacity. The second condition considered the presence of sedimentation, which reduces the effective cross-sectional area and consequently the discharge capacity. This dual analysis enabled a more accurate representation of actual field conditions.

Performance Evaluation

The performance of the drainage system was assessed by comparing the existing discharge capacity (Qs) with the design discharge (Qr). This comparison served as the primary indicator of system adequacy. The evaluation criteria were defined such that the drainage system was considered adequate when the existing capacity was equal to or greater than the design discharge. Conversely, if the existing capacity was lower than the design discharge, the system was categorized as inadequate. In addition to quantitative evaluation, qualitative analysis was conducted to identify non-hydraulic factors contributing to system inefficiency. These factors included sediment accumulation, solid waste blockage, structural damage, and uneven road surfaces that disrupt flow patterns. The integration of quantitative and qualitative assessments provided a comprehensive understanding of drainage performance.

Data Analysis Procedure

The overall analysis followed a structured and sequential procedure to ensure methodological consistency. The process began with data collection, followed by hydrological analysis to estimate rainfall characteristics and design discharge. Subsequently, hydraulic analysis was performed to determine channel capacity under different conditions. The results of both analyses were then compared to evaluate system performance. Finally, physical and environmental constraints were identified, and recommendations were formulated based on the findings. This systematic approach ensured that the evaluation was not only based on theoretical calculations but also supported by actual field conditions, thereby enhancing the reliability and applicability of the results.

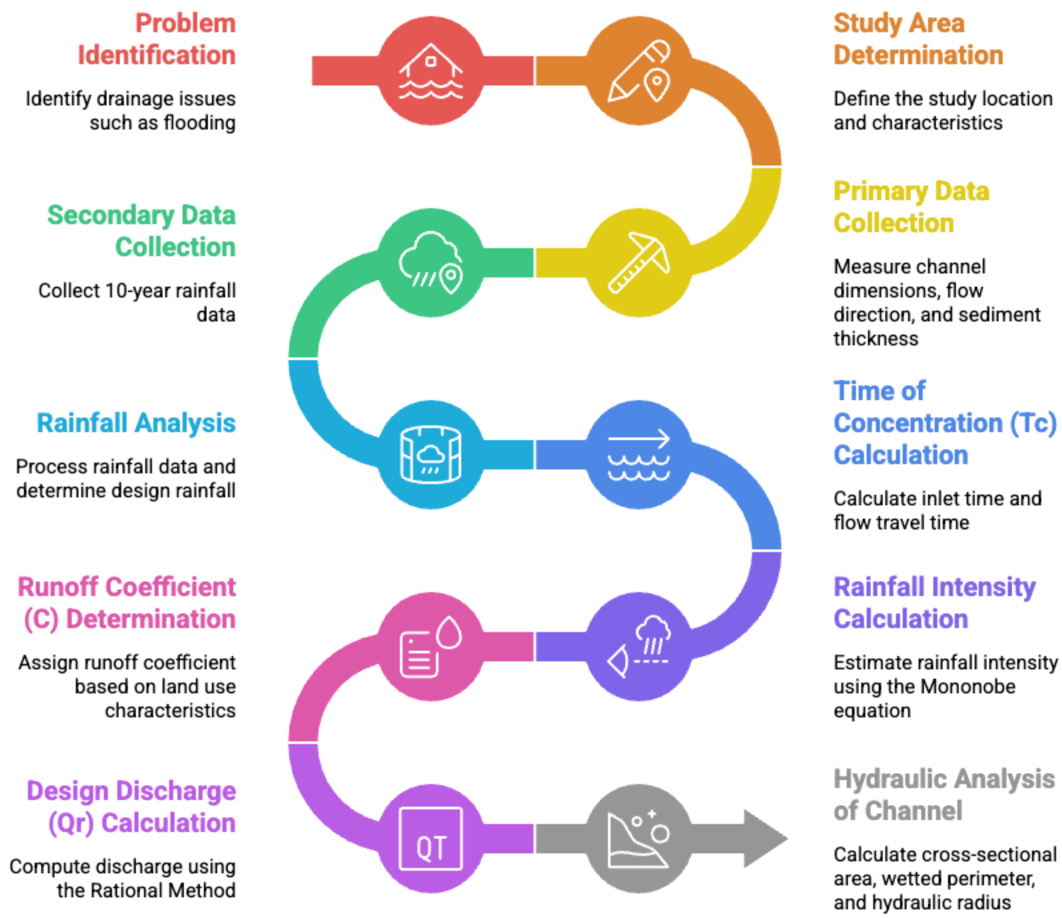

Figure 2. Research Method Flow

RESULT AND DISCUSSIONS

Results

Hydrological Characteristics of the Study Area

The hydrological analysis was carried out using a 10-year record of maximum daily rainfall to determine the design rainfall and its corresponding discharge. The Gumbel distribution method was applied to estimate rainfall magnitude for the selected return period, representing extreme rainfall conditions expected within the study area. The resulting design rainfall value reflects the statistical likelihood of peak hydrological events that significantly influence urban runoff behavior. Rainfall intensity was subsequently calculated using the Mononobe equation, which converts daily rainfall into short-duration rainfall intensity based on the time of concentration (Tc). The calculated Tc, obtained from the combination of inlet time and flow travel time, indicates a relatively rapid hydrological response due to short flow paths and impervious surfaces. This condition leads to higher peak discharge within a shorter duration.

Figure 2. Characteristics of the Study Area

The runoff coefficient (C) was determined based on land use characteristics dominated by residential areas, paved surfaces, and limited infiltration zones. As a result, the coefficient indicates a high runoff potential, meaning that a substantial portion of rainfall is directly transformed into surface flow. The design discharge (Qr) was then calculated using the Rational Method, integrating rainfall intensity, runoff coefficient, and catchment area, along with additional domestic wastewater contributions.

Table 1. Detailed Hydrological Parameters and Calculation Components

Parameter	Symbol	Unit	Description	Condition/Result
Rainfall data period	-	years	Maximum daily rainfall data	10 years
Distribution method	-	-	Probability distribution used	Gumbel
Design rainfall	Xt	mm	Rainfall for selected return period	Calculated
Time of concentration	Tc	minutes	Total flow time (T1 + T2)	Calculated
Rainfall intensity	I	mm/hour	Derived using Mononobe equation	High (short duration)
Runoff coefficient	C	-	Based on land use characteristics	Moderate–High (≈0.6–0.8)
Catchment area	A	km^2	Drainage service area	Local residential area
Domestic wastewater discharge	Qlimbah	m^3/s	Contribution from households	Included
Design discharge	Qr	m^3/s	Total discharge (runoff + wastewater)	Peak design flow

Existing Channel Hydraulic Capacity

Hydraulic analysis was conducted to evaluate the discharge capacity of the drainage system using geometric and flow parameters. The Manning equation was applied to estimate flow velocity and discharge capacity under varying channel conditions. Under ideal conditions (without sedimentation), the channel maintains its full geometric capacity, resulting in optimal hydraulic performance. The calculated cross-sectional area (A), wetted perimeter (P), and hydraulic radius (R) support stable flow conditions, and the resulting velocity remains within permissible limits. Consequently, the discharge capacity (Qs) exceeds the design discharge (Qr), indicating that the channel is capable of handling peak flow conditions as designed. However, under actual conditions where sedimentation is present, the effective cross-sectional area is significantly reduced. This reduction leads to a decrease in hydraulic radius and flow velocity, which ultimately lowers the discharge capacity. The presence of sediment alters the flow regime, increasing resistance and reducing efficiency.

Table 2. Hydraulic Parameters Under Ideal and Actual Conditions

Parameter	**Symbol**	**Unit**	**Ideal Condition (No Sediment)**	**Actual Condition (With Sediment)**	**Impact Description**
Cross-sectional area	A	m^2	Maximum	Reduced	Reduced flow capacity
Wetted perimeter	P	m	Stable	Slightly increased	Increased friction
Hydraulic radius	R	m	Optimal	Decreased	Reduced flow efficiency
Channel slope	S	-	Constant	Constant	No change
Manning roughness	n	-	Standard	Increased (due to sediment)	Increased resistance
Flow velocity	V	m/s	Stable	Reduced	Slower flow
Discharge capacity	Qs	m^3/s	Higher than Qr	Approaching or below Qr	Risk of overflow

Figure 3. Existing Channel Hydraulic Capacity

Segment Based Capacity Evaluation

A segment-wise evaluation was conducted to assess variations in channel performance along the drainage network. The results indicate that while upstream segments tend to maintain better hydraulic conditions, downstream segments are more affected by sedimentation and waste accumulation.

Table 3. Segment Based Comparison of Qs and Qr

Segment	Qs (Ideal)	Qs (Actual)	Qr	Performance (Ideal)	Performance (Actual)
1	>Qr	≈Qr	Qr	Adequate	Marginal
2	>Qr	<Qr	Qr	Adequate	Inadequate
3	>Qr	<Qr	Qr	Adequate	Inadequate
4	>Qr	≈Qr	Qr	Adequate	Marginal
5	>Qr	<Qr	Qr	Adequate	Inadequate

Comparison Between Existing Capacity and Design Discharge

The comparison between Qs and Qr clearly demonstrates that the drainage system performs differently under ideal and actual conditions. In the absence of sedimentation, Qs consistently exceeds Qr, confirming that the channel design is hydraulically sufficient. However, when sedimentation is considered, the discharge capacity decreases significantly, and in several segments, Qs falls below Qr. This condition indicates that the system is vulnerable to overflow during peak rainfall events. The reduction in discharge capacity highlights the importance of maintaining channel geometry to preserve hydraulic performance.

Field Observations of Physical Conditions

Field observations revealed that physical and environmental factors significantly influence drainage performance. Sedimentation was identified as the primary factor reducing channel capacity, particularly in low-slope segments where flow velocity is insufficient to transport sediments. Solid waste accumulation was also observed, causing partial blockage and increasing flow resistance. Structural damage, such as cracked channel walls and irregular surfaces, disrupts flow continuity and contributes to energy loss. Additionally, uneven road surfaces affect the distribution of runoff, leading to inefficient drainage patterns.

Table 4. Physical Factors and Their Hydraulic Impacts

Factor	Description	Hydraulic Impact	Severity Level
Sedimentation	Deposits at channel base	Reduces cross-sectional area	High
Solid waste	Plastic, organic debris	Causes blockage and turbulence	High
Structural damage	Cracks, erosion	Disrupts flow continuity	Medium
Vegetation growth	Plants inside channel	Increases roughness	Medium
Uneven road surface	Irregular elevation	Alters runoff direction	

Overall Drainage System Performance

The overall evaluation indicates that the drainage system is hydraulically adequate under ideal conditions but fails to maintain its performance under actual field conditions. The discrepancy between theoretical and actual capacity is primarily caused by sedimentation, waste accumulation, and lack of routine maintenance. These findings demonstrate that drainage system effectiveness is not solely dependent on design capacity but also on operational conditions. Without proper maintenance and management, even well-designed systems may fail to function effectively.

The results of this study demonstrate that the drainage system is hydraulically adequate under ideal conditions, yet its performance declines significantly under actual field conditions due to physical disturbances. This finding highlights the critical distinction between theoretical design capacity and operational functionality in urban drainage systems [33], [34]. The calculated design discharge (Qr), derived from hydrological parameters such as rainfall intensity, runoff coefficient, and catchment characteristics, represents peak flow conditions that the system is expected to handle. Under sediment-free conditions, the existing discharge capacity (Qs) exceeds Qr, indicating that the original design is technically sufficient. However, the introduction of sedimentation alters the effective hydraulic parameters, particularly the cross-sectional area and hydraulic radius, leading to reduced flow efficiency [35], [36]. This observation aligns with previous studies that emphasize sediment accumulation as a primary factor in reducing drainage capacity in urban environments [37], [38], [39]. For instance, research on urban drainage systems in Southeast Asia has shown that even minor sediment deposition can significantly decrease flow capacity and increase flood risk. Similarly, studies in tropical regions have reported that high rainfall intensity combined with poor maintenance accelerates sedimentation processes [40], [41], [42]. The present findings reinforce the argument that hydraulic design alone cannot guarantee system performance without considering long-term operational conditions. Therefore, the discrepancy between ideal and actual performance observed in this study reflects a broader issue commonly reported in urban drainage research.

In addition to sedimentation, the study identified solid waste accumulation and structural deterioration as key factors influencing drainage inefficiency. These non-hydraulic factors contribute to increased flow resistance and partial blockage, thereby reducing the effective discharge capacity of the channel. The presence of waste materials, such as plastics and organic debris, disrupts flow continuity and creates localized turbulence, which further impedes water conveyance. This phenomenon has been widely documented in previous studies, where improper waste management is identified as a major contributor to urban flooding. For example, research conducted in densely populated urban areas indicates that drainage systems often fail not due to inadequate design, but due to blockages caused by anthropogenic waste. Moreover, structural damage, including cracks and irregular channel surfaces, increases roughness coefficients and reduces flow velocity, consistent with hydraulic theory. Similar findings have been reported in studies evaluating aging drainage infrastructure, where deterioration leads to significant energy losses and reduced system efficiency. The influence of uneven road surfaces observed in this study also supports previous research indicating that improper surface grading can alter runoff pathways and reduce drainage effectiveness. Collectively, these factors demonstrate that drainage performance is strongly influenced by both engineering and environmental conditions. The consistency of these findings with prior studies suggests that the issues identified are not site-specific but represent common challenges in urban drainage management.

Furthermore, the comparison between Qs and Qr across different channel segments reveals that drainage performance is spatially variable and highly sensitive to local conditions. Segments with minimal sedimentation and obstruction maintain adequate capacity, while those affected by physical constraints exhibit reduced performance and increased flood risk. This spatial variability is consistent with findings from previous studies that emphasize the importance of segment-level analysis in drainage evaluation. Research in urban hydrology has shown that localized bottlenecks, rather than system-wide deficiencies, are often responsible for flooding events. The results of this study support this perspective, as only certain segments exhibited Qs values lower than Qr under actual conditions. This indicates that targeted interventions, rather than complete system redesign, may be more effective in improving drainage performance. Additionally, the findings underscore the importance of integrating maintenance strategies into drainage system management. Previous studies have demonstrated that regular cleaning and sediment removal can restore channel capacity to near-design conditions. The present study confirms that the lack of maintenance is a major contributor to performance degradation. Therefore, improving operational practices, alongside maintaining structural integrity, is essential for ensuring long-term drainage efficiency. Overall, this study contributes to the growing body of literature emphasizing that sustainable urban drainage management requires a balance between design adequacy and continuous maintenance.

CONCLUSION

This study evaluated the performance of an urban drainage system by integrating hydrological and hydraulic analyses with field observations. The results indicate that the drainage channel is hydraulically adequate under ideal conditions, as the existing discharge capacity exceeds the calculated design discharge. However, under actual field conditions, the system performance is significantly reduced due to sedimentation, waste accumulation, and structural deterioration. The hydrological analysis shows that the study area is characterized by high runoff potential, driven by intense rainfall and limited infiltration capacity. Consequently, the drainage system is required to accommodate substantial peak discharge during rainfall events. The hydraulic analysis demonstrates that sedimentation reduces the effective cross-sectional area and flow efficiency, leading to decreased discharge capacity. The comparison between existing capacity and design discharge confirms that several channel segments become inadequate when sedimentation is present. Field observations further reveal that non-hydraulic factors, including solid waste and uneven road surfaces, exacerbate drainage inefficiency. These findings suggest that the discrepancy between design performance and actual conditions is primarily caused by operational and environmental factors rather than design limitations. Therefore, maintaining channel cleanliness and structural integrity is essential to ensure optimal drainage performance. The study highlights the importance of integrating regular maintenance practices with engineering design in urban drainage management. Overall, sustainable drainage system performance requires a balanced approach that combines adequate design capacity, proper maintenance, and community participation.

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AUTHORS CONTIBUTIONS

Imanuel Kemenangenta Perangin Angin conceived the research idea, supervised the overall study, and provided critical guidance in the development of the research design, methodology, and technical analysis. Doni Febriawan contributed to data collection through field observations, performed hydrological and hydraulic analyses, and prepared the initial draft of the manuscript. Rendy assisted in data processing, supported field measurements, and contributed to the analysis of drainage system conditions and visualization of results. Jeremia Dinata Perangin Angin contributed to the conceptual refinement of the study, assisted in interpreting the results within a broader scientific context, and provided critical revisions to improve the clarity, structure, and academic quality of the manuscript. All authors discussed the results, contributed to the final version of the manuscript, and approved the submitted version.

CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest related to the design, implementation, analysis, or publication of this research. All procedures were conducted independently, and no financial or personal relationships have influenced the outcomes presented in this article.

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